

# SPECIFICATION

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## **METHOD AND APPARATUS FOR REAL TIME DISPLAY OF FILTERED ELECTROCARDIOGRAM DATA**

### **Background of Invention**

[0001] The present disclosure relates generally to methods of real time display of filtered waveform data and, more particularly, to a method and apparatus for real time display of filtered electrocardiogram data.

[0002] An electrocardiogram (ECG) of a cardiac cycle is detected across sense electrode pairs located on the surface of a patient's body, and is a repetitive waveform characterized by a periodic PQRS electrical activation sequence of the upper and lower heart chambers. The PQRS sequence is associated with the sequential depolarization and contraction of the atria followed by the depolarization and contraction of the ventricles, and successive PQRS complexes are separated by a baseline or isoelectric region.

[0003] As shown in Figure 1, The PQRS electrical activation sequence commences with the P-wave, which is indicative of the depolarization and contraction of the atria. Following is the QRS complex, which is indicative of the depolarization and contraction of the ventricles. The T-wave at the termination of the ST segment time delay is associated with re-polarization of the ventricles. The PQRS electrical activation sequence with intact A-V activation detected across a sense electrode pair is fairly predictable in shape. The P-wave, R-wave and T-wave events occurring in sequence in the range of normal heart rates are usually readily recognized by visual examination of the external ECG recorded by applied body surface electrodes that are



partial baseline correction thereof, while the data displayed in the second portion has a corrected baseline amplitude adjustment with no further amplitude level adjustment applied thereto.

[0007] In another aspect, a method of filtering and displaying sequential waveform data samples includes shifting a sequence of stored uncorrected data samples, and then receiving and storing a new uncorrected data sample. A baseline estimate correction is computed using the stored uncorrected data samples and the new uncorrected data sample. Then, a sequence of stored corrected data samples is shifted and a new corrected data sample is determined by applying the baseline estimate correction to a specific one of the stored uncorrected data samples. A sequence of temporary display data samples is created by applying the baseline correction to each of the stored uncorrected data samples that were stored subsequent to the specific stored uncorrected data sample, as well as to the new uncorrected data sample. Then, the sequence of corrected data samples, the new corrected data sample, and the sequence of temporary display data samples are each displayed.

[0008] In still a further aspect, an electrocardiogram (ECG) system includes a set of electrodes for detecting ECG signals from a subject and signal condition circuitry for conditioning the ECG signals detected by the set of electrodes. A processor is used for processing conditioned signals from the signal condition circuitry. In addition, a display for displaying ECG waveform data produced by the processor further includes a display region having a first portion and a second portion immediately adjacent to the first portion. The first portion is used to display a first segment of the waveform data representing the most recently received data extending back to a determined delay period, while the second portion is used to display a second segment of the waveform data representing the remainder of the waveform data. The waveform data displayed in the first portion has a continuously varying amplitude level adjustment applied thereto for partial baseline correction thereof, and the data displayed in the second portion has a corrected baseline amplitude adjustment with no further amplitude level adjustment applied thereto.

## Brief Description of Drawings

[0009] Referring to the exemplary drawings wherein like elements are numbered alike in

$\frac{1}{n} \sum_{j=1}^n \left( \frac{\partial}{\partial x_j} - \frac{x_j}{2} \right) f(x) = 0$ ,  $\frac{1}{n} \sum_{j=1}^n \left( \frac{\partial}{\partial y_j} - \frac{y_j}{2} \right) f(x, y) = 0$

[0010] Figure 1 is a schematic representation of an ECG waveform;

[0011] Figure 2 is a schematic block diagram of an exemplary ECG system suitable for practicing an embodiment of the present disclosure;

[0012] Figures 3(a) through 3(f) are waveform displays illustrating conventional data filtering techniques as applied to a square wave noise disturbance;

[0013] Figure 4 is a schematic diagram illustrating an exemplary data filtering and display technique, in accordance with an embodiment of the invention;

[0014] Figure 5 is a flow diagram further illustrating the data filtering and display technique shown in Figure 4;

[0015] Figures 6(a) and 6(b) are waveform displays illustrating the results of the application of the inventive data filtering and display technique to the square wave noise disturbance;

[0016] Figures 7(a) through 7(c) are waveform displays illustrating conventional data filtering techniques as applied to random, low frequency noise disturbance;

[0017] Figures 8(a) through 8(h) are waveform displays illustrating the results of the application of the inventive data filtering and display technique to random, low frequency noise disturbance; and

[0018] Figures 9(a) through 9(e) are waveform displays comparing the results of the inventive data filtering and display technique and the conventional techniques as applied to a repeated example of the same actual ECG data.

### Detailed Description

[0019]

Disclosed herein is a method and apparatus for real time display of filtered electrocardiogram data. Briefly stated, a delayed symmetrical finite impulse response filter (FIR) is implemented to produce a continuously adjusted DC level portion of a display region. A continuous scrolling display is thereby provided in which a first portion of the display features a more recent portion of the overall waveform data

having a continuously level adjusted, partially corrected baseline. In addition, a second portion of the display features an earlier portion of the overall waveform data having a substantially corrected baseline that scrolls at constant amplitude. As a result of this technique, the ST segment of a displayed ECG waveform remains undistorted:

[0020] In one embodiment, the symmetrical FIR is designed to be, in effect, a triangular impulse response with a total width of a little more than 2 seconds. Accordingly, a delay of about 1 second is implemented before filtering and thus the continuously adjusted DC level portion (i.e., the first portion) of the display region is at the right side of the display, covering a display distance of approximately one second. However, the delay may be implemented over a larger time range from about 0.5 seconds to about 3.0 seconds. Conventionally, for ECG systems, new data enters onto the display area at the right edge thereof while older data scrolls across the area in a leftward direction. In order to implement the baseline correction, the first portion of the display area is completely repainted every screen refresh time while, in contrast, the data shown in the second portion of the display area is simply scrolled (i.e., shifted to the left) by a constant count of pixels every refresh time. Such a display is possible with modern computer video displays capable of repainting the entire screen every vertical refresh period (approximately 70 times per second).

[0021] Referring initially to Figure 2, there is shown an exemplary ECG system 100 suitable for practicing an embodiment of the present disclosure. The system 100 may, for example, be used in a clinical setting or perhaps during the physiologic stress testing of a patient's heart. In an exemplary embodiment, the system 100 includes a set 105 of electrodes 110, which may be standard ECG electrodes, or possibly an array of electrodes applied to cover the anterior, lateral and posterior areas of the patient's torso. While the electrodes 110 function separately from one another, they may be physically affixed together to form a flexible band or other arrangement.

[0022] In addition, the system 100 further includes a set of leads 115 that connect the electrodes to a system controller 120. The controller 120 includes signal conditioning circuitry 125 and a processor 130. The signal conditioning circuitry 125 receives analog signals from the leads 115 as inputs thereto, and provides as outputs conditioned digital signals to the processor 130. In turn, the processor 130 processes

the conditioned signals to produce output results thereafter provided to a connected display 135 and/or to an output device 140, such as a printer. If used in a stress testing application, the processor 130 may further control an exercise device, such as a treadmill 145 having a programmable slope and walking speed, through control signals supplied through a cable 150. Similarly, an optional recording device 155 of an ambulatory system may be used to record signals from the leads for an extended period of time (e.g., 24 hours). The recording device 155 then is connected to the controller 120 to permit the controller 120 to process the recorded data.

[0023] As stated previously, there are existing problems associated with the real time display of conventionally filtered ECG data, which are particularly illustrated by way of a fairly simplified example. Referring now to Figures 3(a) and 3(b), there is shown a pair of waveform displays of a periodic triangular impulse that mimics the general shape of the QRS complex. The upper waveform, as indicated in the figures, represents the raw signal disturbed by square wave noise, while the lower waveform represents the same signal (also disturbed by square wave noise) as filtered by a 0.037 Hz high pass filter. As can be seen, while the 0.037 Hz filter preserves the integrity of the triangular pulse, it is slow to respond with respect to returning the waveform back to its baseline level. When the square wave noise is removed, as shown in Figure 3(b), the waveform drops below the baseline and is slow in returning upward back to the baseline.

[0024] In contrast, when a 0.597 Hz high pass filter is used, there is a much quicker return to the baseline, as shown in Figures 3(c) and 3(d). However, it will also be noted that this filter distorts the falling edge of the triangular impulse by dipping it below the level of the beginning of the rising edge. Unfortunately, such a distortion could result in an inaccurate interpretation of an actual ECG reading. Thus, this particular type of aggressive filtering of the waveform is equally as undesirable as a slow response time. Still another type of filtering technique is what is referred to as parabolic baseline correction, and is illustrated in Figures 3(e) and 3(f). As can be seen, the parabolic baseline correction does not result in as much distortion as the 0.597 Hz high pass filter, but it is also not as aggressive in returning the waveform to the baseline.



[0028] The symmetrical FIR filter uses all 511 of the unfiltered samples, centered on sample  $X_{t-255T}$ , to compute an average baseline estimate for every screen refresh. Then, the computed baseline estimate,  $B$ , is subtracted from data sample  $X_{t-255T}$  to produce  $Y_{t-255T}$  which, as stated earlier, is passed directly to the display buffer as  $D_{t-255T}$ . Furthermore, the computed baseline estimate  $B$  is also used in displaying the most recent 255 samples ( $D_t$  through  $D_{t-254T}$ ). This is the data contained in the continuously adjusted DC level portion (i.e., the first portion) of the display region at the right side of the display 135, covering a display distance of about one second.

[0029] Referring now to Figure 5, there is shown a flow diagram 300 illustrating the process by which the method operates to receive new ECG waveform data and display the new data, along with the most recent data samples. Beginning at block 302, each of the previously stored 511 unfiltered data samples in the unfiltered data buffer 206 is shifted over (with the previously oldest sample at  $X_{t-510T}$  being eliminated). This clears the way for a new, uncorrected ECG data sample to be received in the unfiltered data buffer 206 at  $X_t$ , as shown at block 304.

[0030] Once the newest ECG sample is received at  $X_t$ , a new baseline estimate from the current 511 unfiltered samples is computed, as shown at block 306. This may be represented by the convolution expression:  $B = \text{FIR}_{\text{lowpass}} * X_{t-nT}$  (for  $n = 0$  to 510). Then, at block 308, the previous data samples (1184 total) in the filtered data buffer 202 are shifted over to make room for the data sample shifted out of the storage element 204 that holds the sample data designated  $Y_{t-255T}$ . In turn, the storage element 204 is now clear to accept the latest corrected sample based on the newly computed baseline estimate  $B$ , wherein as stated earlier:  $Y_{t-255T} = X_{t-255T} - B$ . This step is shown at block 310. As also stated previously, the method proceeds to block 312, where additional "temporary" display samples are created from the most recent 255 unfiltered data samples (i.e.,  $X_t$  through  $X_{t-254T}$ ) by subtracting  $B$  therefrom. Finally, at block 314, the entire display area is refreshed using the updated 1185 corrected samples and the 255 temporary display samples loaded into the display buffer 200. The source of the data sample  $D_{t-nT}$  loaded into the display buffer 200 is described by:

$$\begin{aligned} D_{t-nT} &= X_{t-nT} - B \quad (\text{for } n = 0 \text{ to } 254) \\ D_{t-nT} &= Y_{t-nT} \quad (\text{for } n = 255 \text{ to } 1439) \end{aligned}$$



[0031] The effects of the above described method are best appreciated through observation of a moving, dynamic view of a waveform as it is scrolled across a display. Nonetheless, Figures 6(a) and 6(b) are somewhat illustrative of the performance of the data display method as applied to the triangular impulse/square wave disturbance examples used in Figures 3(a)–3(f). As will be noted, the baseline correction actually begins before the rising edge of the square wave in the raw signal, and thus the initial baseline shift upward is only roughly half that of the unfiltered waveform. This is the result of the delayed baseline correction through the symmetrical FIR filter that uses the unfiltered data samples occurring before and after the correction point of the display. It will also be noted that the time taken in returning to the baseline is favorable as compared to the aggressive 0.597 Hz filter (Figures 3(c) and 3(d)), only without the signal distortion.

[0032] A more realistic example of random, low frequency noise imposed on the triangular impulse waveform is shown in Figures 7(a)–7(c). Figure 7(a) illustrates the performance of the 0.037 Hz filter versus the unfiltered raw signal. As is shown, the 0.037 Hz filter provides very little improvement in baseline correction, with the impulses from the filtered signal being only marginally closer to the baseline than the unfiltered raw signal. In Figure 7(b), the 0.597 Hz filter provides a much better baseline correction of the random noise, but again there is more distortion of the triangular QSR impulse itself. Once again, the parabolic baseline correction technique shown in Figure 7(c) provides a tradeoff between baseline correction and signal distortion, but is still not as aggressive as is desirable.

[0033] In contrast, the performance of the present method on the random noise is illustrated in Figures 8(a) through 8(h), which are sequential images taken from a computer display screen as the waveforms are scrolled over time. In this demonstration program, the computer display screen is divided into a first portion 404 and a second portion 402, separated by the dashed line 406. It should be noted that the actual time division shown between the first and second portions of the computer display screen, being exemplary in nature, does not necessarily correspond to the specific 1440 sample display described earlier. Rather, the significance of Figures 8(a) through 8(h) lies in the different display techniques between the first and second portions.

[0034] Figure 8(a) is the first image taken at an initial time  $t_0$ , wherein a first, raw signal triangular impulse  $\delta(0)$  appears at the right side of the display. The corresponding filtered impulse, labeled  $\delta'(0)$ , is shown on the first portion 404 of the display screen. The second portion 402 of the display screen will scroll the waveform data in a conventional manner, while the first portion 404 provides the continuous DC level correction.

[0035] Figure 8(b) is the screen shot taken at time  $t_1$ . As is shown, the position of  $\delta'(0)$  with respect to the baseline has changed from its position at time  $t_0$  (shown in phantom) by moving downwardly. This reflects the active baseline correction taking place within the first portion 404 of the display. More particularly, the specific baseline correction is determined by the symmetric FIR filtering, centered at dashed line 406. However, in the second portion 402 of the display, there has been no amplitude change in the filtered signal with respect to time as it is simply scrolling across. The next sequential shot is shown in Figure 8(c), taken at time  $t_2$ . (It should be noted at this point that the specific time intervals between the figures are not necessarily taken at equally spaced time intervals, as the present examples are only meant to be illustrative in nature.) Once again, the position of  $\delta'(0)$  has continued to decrease slightly with respect to the baseline as compared to its position at  $t_1$  and  $t_0$ . Were the display to be viewed in real time between  $t_0$  and  $t_2$ , the impulse  $\delta'(0)$  would appear to be descending as it moves from right to left. At the same time, there would be no amplitude change in that part of the filtered waveform located in the second portion 402 as it moves from right to left.

[0036] Referring now to Figure 8(d), a new impulse  $\delta(1)$  has appeared in the raw signal waveform at time  $t_3$ , along with the corresponding filtered impulse  $\delta'(1)$  in the first portion 404 of the display. By this time,  $\delta'(0)$  has scrolled over to the second portion 402, and will no longer be subjected to an amplitude correction for the remainder of its scroll time across the display. Meanwhile, in Figure 8(e) taken at time  $t_4$ , the impulse  $\delta'(1)$  has ascended with respect to the baseline between  $t_3$  and  $t_4$ . During this time, it will be noted that  $\delta'(0)$  has not changed its amplitude position now that it resides in the second portion 402 of the display.

[0037] Moving forward to Figure 8(f) at time  $t_5$ , it can be seen that  $\delta'(1)$  has now

dynamically descended from its position at  $t_4$  as it is about to cross from the first portion 404 over to the second portion 402. In addition, a new impulse  $\delta'(2)$  (and  $\delta''(2)$ ) has appeared at the rightmost portion of the display. It is further noted that the amplitude position of  $\delta'(0)$  has remained the same as it moves still further to the left. Then, in Figure 8(g), taken at  $t_6$ , there is illustrated the downward baseline correction movement of  $\delta'(2)$  while it remains in the first portion 404. Again, both  $\delta'(1)$  and  $\delta'(0)$ , being in second portion 402, do not shift with respect to the baseline. Lastly, Figure 8(h) is a screenshot taken at time  $t_7$ , wherein it is seen that  $\delta'(2)$  was swept back upward before scrolling over to the second portion 402. A new waveform  $\delta'(3)$  now appears in the first portion 404, while  $\delta'(0)$  has completely scrolled off the left side of the display. Thus, by viewing Figures 8(a) through 8(h), a measure of appreciation for the "whiplike" corrective action in the first portion 404 of the display is attained.

[0038] Finally, the results of the present method are compared with the previously discussed conventional filtering techniques, as applied to actual ECG wave forms shown in Figures 9(a) through 9(e). In Figure 9(a), there are three individual ECG raw signal readings, wherein the random noise has actually caused the lower two waveforms to cross over one another. In Figure 9(b), the same noise has not been effectively remedied by the 0.037 Hz high pass filter, as the two lower waveforms are still crisscrossed. The 0.597 Hz high pass filter does provide the aggressive base line correction by untangling the lower two waveforms in Figure 9(c), but again the signal distortion can lead to a misinterpretation of the ECG. In Figure 9(d), the parabolic baseline correction is relatively ineffective like the 0.037 Hz filter. However, Figure 9 (e) shows that the present method is most effective in removing baseline drift without distorting the ECG.

[0039] The applicability of the above described method includes all real-time cardiac monitors, invasive electrophysiological (EP) systems, exercise stress test machines, defibrillators, and ECG carts with a real-time rhythm mode and CRT or LCD displays. However, the data filtering and display techniques are not limited to display of ECG data, but may generally apply to any system in which it is desired to display waveform data in real time, such as plethysmograph data, blood pressure data or geologic/seismic data, for example.



this invention, but that the invention will include all embodiments falling within the scope of the appended claims.